STUDY OF SOME ALPHA GROUPS FROM AMERICIUM—241

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ABSTRACT. Alpha decay of Americium-241 has been investigated with a low pressure expansion cloud chamber. It has been possible to measure the energies and relative abundances of at least 5 alpha ray groups. Based on these experimental data a partial level scheme for Neptunium-237 is presented and discussed.

INTRODUCTION

Alpha radioactivity has been observed to be a property common to all the elements beyond lead in the periodic classification of elements. The alpha particles from a given radioactive nuclide are emitted in groups with discrete energies. Investigation on the α-decay characteristics of several α-emitters has revealed certain interesting features common to them. Thus in the case of all even-even α-emitters it has been found that transitions to the ground state of the product nucleus is most abundant, whereas transitions by a lower energy group is in lower abundance. These observations are in good agreement with the demands of the simple α-decay theory presented by Gamow. There is, however, a good deal of departure from this regularity in the case of odd nucleon type. It is noticed that for the odd nucleon type, the ground state transition is most highly hindered, whereas one or more of the lower energy groups are in relatively higher abundance than would be expected on the basis of their respective energies. For example, in the case of Am^{241} which is of the odd-even type, analysis of the fine structure α-ray groups in transitions to different excited levels of Np^{237} shows that the highest energy α-group leading to the ground state is in very poor abundance compared to 85% abundance of a lower energy group leading to a level 59 keV above the ground state A detailed knowledge of the energy of the several α-ray groups and their abundances can possibly lead to a better understanding of the complex behaviour of such odd-even species in particular and eventually advance our ideas in the realisation of a rigid α-decay theory. We choose Am^{241} as a good representative of the odd-even species for making our investigations. Besides the intrensic interest in the α-decay characteristics of Am^{241}, the energy differences of the various α-groups involved allow us to picture a level scheme of the excited states of Np^{237}. Neptunium is one of the most widely studied nuclei. Information on the excited states of Np^{237} has been obtained mostly through experiments based on (i) β-decay of U^{237}, Baranov (1956), Rasmussen (1957), Bunker (1957) (ii) electron capture in Pu^{237}, Haffmen (1958), (iii) coulomb excitation of Np^{237}, Newton (1958). Such information has also been obtained by Wolfson (1964) through studies on the low energy γ-ray transitions in Np^{237} following the α-decay of Am^{241} by an examination of the internal conversion spectrum. However, relatively much less is known about the excitation levels of Np^{237} from direct measurements on α-transitions in the decay of Am^{241}. Asaro *et al.* (1952) and Rosenblum (1957) have reported α-transitions measured directly to seven Np^{237} levels. The recent investigations of Baranov (1964), using a magnetic spectrograph of high resolution, has considerably enhanced our knowledge by revealing the existence of a strikingly large number of α-ray groups hitherto unknown.

In view of the recent findings, Am^{241} offers a worthwhile study from the view point of the intrinsic characteristics of α-decay as well as the excitation levels of Np^{237} appearing through the α-decay of Americium. A low pressure expansion cloud chamber has been used for resolving several of the α-groups emitted by Am^{241}. Their relative intensities have also been estimated Based on these experimental data a partial level scheme of Np^{237} is presented.

APPARATUS AND EXPERIMENTAL ARRANGEMENT

A low pressure expansion type cloud chamber reported by the author in an earlier publication (1961) has been used in determining the energies of the various α-ray groups from measurements of their respective ranges. The dimensions of the chamber are 25 cm in diameter and 5 cm in depth Argon and iso-amyl alcohol is the gas-vapour mixture used for the chamber filling. The working pressure of the chamber has been maintained at $\simeq$ 15 cm Hg. By such a choice of the gas-vapour composition and the working pressure inside the chamber it is possible to magnify the track lengths of the α-particles so as to extend almost across the entire diameter of the chamber. In so doing, the range differences of the various α-ray groups are accentuated, thus facilitating more precise measurements on the ranges and consequently better energy estimates.

The source for investigation is isotopically pure Am^{241} obtained from Oak Ridge Technical Enterprises Corporation (ORTEC), Tennessee. Deposited on a platinum backing, the active source diameter is 3 mm and has a strength of 0.154 μ Cur. This source has been mounted on the wall of the perspex chamber internally. An electrochemically deposited source of polonium of low activity has also been installed inside the chamber so as to photograph suitable reference tracks along with α-ray tracks of Am^{241}. In order to avoid jamming every picture with Po-α tracks, thereby making measurements on Am^{241} alphas less cumbersome, the Po-alphas were interrupted by a shutter arrangement operated electromagnetically so that the reference tracks were only introduced into the picture at chosen intervals. Such an arrangement would help to checkup the constancy of pressure over the entire operating period of the chamber.

The α-tracks are photographed under a stereo set-up. For a spatial reconstruction of the tracks, the developed negatives are reintroduced into the same camera assembly and strongly illuminated so as to project the images on a translucent viewing screen arranged to be conveniently adjusted to any desired plane. The screen is so oriented that the image of a given track as projected from the two lens system of the camera is observed to coincide throughout, thus re-establishing the original position of a track relative to the camera assembly. Measurement of the true length of a track under investigation is made from the life-size image thus produced.

EXPERIMENTAL RESULTS

With the above setup 4000 stereo photographs were obtained, each picture having on an average about 15 tracks, thus accounting for a total of nearly 60,000 tracks during the whole run. Fresh chamber filling was made every day so as to keep the gas-vapour composition identical, and it was ensured that all the other working conditions were maintained steady all through. After applying the standard criteria for selection of tracks, the number of acceptable tracks reduced to about 35,000 and length measurements were confined only to this number. Accuracy no better than 0.5 mm in length measurements has been attempted. The data are presented in Fig. 1 in the form of length distribution curve

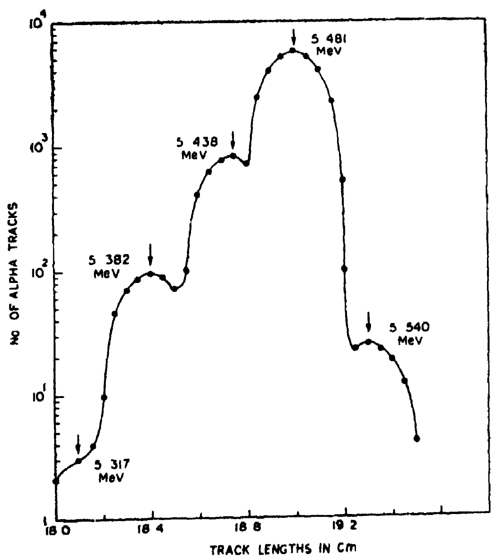

Fig. 1. Track length distribution for Am^{241} α-particles.

The mean values of the ranges in cm corresponding to the different energy groups as obtained from the track length distribution curve are presented in column 1 of Table I.

TABLE I

Data on alpha decay of americium-241

Measured ranges of α-particles (cm)	Reduced air equivalent ranges (cm)	α-particle energy (MeV)	Obs. rel. Intensity %	Calc. rel. Intensity %	Energy level (keV)
19.30	4.110	5.540	—	—	0
19.00	4.047	5.481	85.0	85.6	59.6
18.75	3.993	5.438	12.8	12.2	103.0
18.40	3.919	5.382	1.45	2.2	158.6
18.10	3.855	5.317	–	–	226.0

These mean ranges of the track lengths have been converted to cm of air equivalent range by using the stopping power of the gas. If the stopping power of the gas is defined as the ratio of the mean range of α-particles in air to the range in the gas under the working conditions. then the reduced air ranges are obtained by multiplying the measured lengths by this factor. The stopping power has been experimentally determined in a preliminary investigation by obtaining the mean range of Po-α particles and comparing it with the known mean range of Po-α particles in air under standard conditions (3.84 cm at 760 mm Hg and 15°C). The stopping power has been determined to be 0.213. The choice of Po^{210} alphas is appropriate for this purpose firstly for the reason that the tracks rendered by the source are homogeneous and secondly the energy of Po-α (5.303 MeV) is comparable to that of Am^{241} alphas so that the value of the stopping power deduced can directly be employed in reducing the Am^{241} data without involving serious error.

The reduced air equivalent ranges are shown in column 2 of Table 1. The energies corresponding to the different range groups are obtained by utilising Bethe's range-energy curves, Bethe (1950), and these are given in column 3.

DISCUSSION OF THE RESULTS

The energy level scheme of Np^{237} based on our experimental results is shown in Fig. 2.

We have been able to measure the energies of five groups of α-particles. The different groups are associated with transitions to levels belonging to two rotational bands. The 59.6, 103, 158.6 and 226 KeV levels constitute members of the most highly developed band based on 5/2—[523] orbital in terms of Nilsson's theoretical single particle states. The spin of the lowest member of this band is 5/2. The other rotational band 5/2+[642] comprises of the ground state and the 33KeV level. The 33 KeV level with a reported intensity of 0.24% occurs at a distance of only 26 KeV from a line whose intensity is 85% (roughly 350 times stronger).

The inadequate resolution of the apparatus has made it difficult to resolve this level at 33 KeV. The ground state spin of Np^{237} has been measured by Tomkins (1948), as 5/2. Hollander *et al.* (1956) have assigned parity to the ground state band and the 59 KeV band to be respectively even and odd.

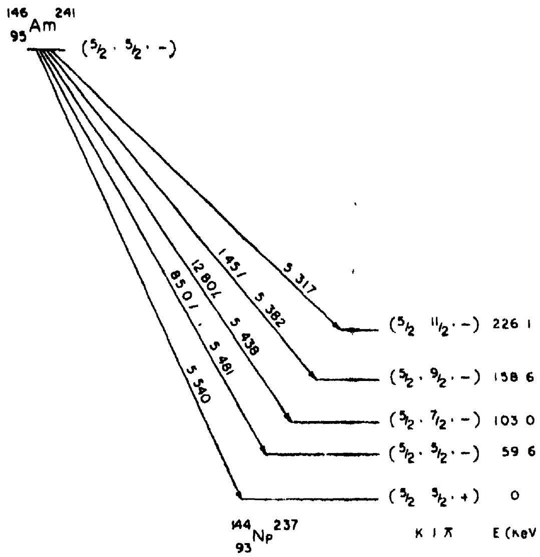

Fig. 2. Energy level scheme of Np^{237}

According to the theory of Bohr and Mottelson (1953), the rotational states of an odd nucleus can have the following energy and spin sequence :

$$E_I = \frac{\hbar^2}{2g}\,[I(I+1)-I_0(I_0+1)]$$

$$I = I_0,\ I_0+1,\ I_0+2, \ldots$$

where I_0 is the spin of the lowest state in the band

I is the spin of the considered excited state and

g is the effective nuclear moment of inertia.

Making use of the energy difference of 43 KeV between the 5/2 and 7/2 states, the quantum of rotation $\frac{\hbar^2}{2g}$ has been calculated to be 6.14 KeV. Again, utilising the energy difference of 56 KeV between the 7/2 and 9/2 states, the calculated value of $\frac{\hbar^2}{2g}$ comes out to be 6.22 KeV. We thus notice the good agreement of the energy level spacings between levels of this band in conformity with Bohr-Mottelson theory for rotational excitation energies.

Further, denoting by I_i, K_i (I_f, K_f) the spin and its projection on the symmetry axis of the initial (final) nucleus. the probability of a favoured α-transition for an odd mass nucleus is given by the formula Bohr. (1955)

$$P = P_0(Z, E)\sum_l C_l < I_i\, l\, K_i\, 0 \,|\, I_i\, l\, I_f\, K_f >^2 \qquad \ldots \quad (1)$$

where $P_0(Z, E)$ is given by Geiger-Nutall law :

$$\log_{10} P_0 = C - DE^{-\frac{1}{2}} \qquad \ldots \quad (2)$$

The constants C, D and C_l are determined from the the α-transition probabilities of the neighbouring even-even nuclei. E is the energy of the fine structure component in question. The bracketted term in the formula (1) is the vector addition of the angular momenta I_i and l to form the resultant I_f. Utilising $C_0 = 1$, $C_2 = 0.7$ and $C_4 = 0.01$ and appropriate values for spins of initial and final states of the nucleus, the relative intensities of the α-transitions to different excited states have been calculated and these are presented in column 5. Five energy peaks are evident from Fig. 1, thereby revealing 5 fine structure α-ray groups from Am^{241}. The relative intensities of 3 levels of the favoured band as estimated from the full--energy peaks of the spectrum are presented in column 4.

In column 6, the best and undisputed values of the excitation energies are included. It can be seen that there is a fairly good agreement between the observed transition intensities and those calculated with the help of the expression for α-transition probabilities for odd mass nuclei. Thus for transitions involving $l = 0, 2, 4$, our data lends support to the validity of formula (1) for α-transition probabilities of odd mass nuclei.

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